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EFFECTS OF MOUNTAIN STREAM TOPOGRAPHY ON THE ACCURACY OF SMALL PARSHALL FLUMES

February 1990

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16. ABSTRACT

Full-scale 6- and 9-inch Parshall flumes were tested in a 16-foot-long laboratory test facility that simulated steep mountain stream approach flow. Observations and tests indicated that the approach pool length should be cleaned out to limit rock and boulder protrusions to 3 inches. Then a prescribed boulder cluster should be placed at midpool length.

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CONTENTS

TABLES

FIGURES

CONTENTS - Continued

APPENDIX

Page

PURPOSE

Through this study, the Bureau of Reclamation determined the discharge measurement accuracy of small Parshall flumes installed in steep, rough channels with shallow flow. Possible methods to minimize errors caused by these effects were also investigated.

BACKGROUND

The USGS (U.S. Geological Service) needs to measure small mountain stream flow to characterize drainage basins currently under investigation. Parshall flumes were chosen to measure the stream flows because of their history of satisfactory performance in measuring irrigation flow and their acceptance as standard water measuring devices. When installed to specifications, Parshall flumes have an accuracy of ±3 to 5 percent.[1] Most open channel water measurement structures require sufficient upstream pooling to provide good approach flow conditions and provide sufficient drop to prevent too much downstream submergence. Mountain streams often have natural drops where flumes can be perched; therefore, downstream submergence can be avoided for this case. However, poor approach conditions are common. A poor approach can cause large velocity and water surface fluctuations which prevent accurate water depth readings. Poor approach flow can also cause unbalanced channel flow where velocity is concentrated on one side. At the USGS field measurement sites the stream channel geology is pervious and thus subject to percolation of water around and under flow-measuring devices. To minimize the amount of flow that bypasses the measuring structure the depth of water upstream of the structure, the driving force for percolation, must be minimized. This is in direct conflict with the pooling requirements for attaining good approach conditions. Because of these problems, the USGS requested that Reclamation study measurement accuracy of 6- and 9-inch Parshall flumes under approach channel conditions (roughness, geometry, and slope) similar to the natural mountain stream channels at their steam gauging sites.

CONCLUSIONS

Conclusions and recommendations based on literature, observations and calibration data are as follows:

- Large boundary roughnesses can cause flow disturbances affecting flume head readings. The approach channel boulder and rock protrusions should be limited to about 3 inches from the general channel shape. The approach channel area covered by the pool at maximum discharge should be cleared down to this roughness limit. Even this prescribed limit can cause variable flow directions for low flows. Thus, in conjunction with the cleaned channel the Parshall flume should be set with the crest 3 inches above the channel invert.

- Although water measurement handbooks do not require 45° wing walls for flumes 6 inches and smaller, they improved the flow through the flumes considerably. The wing walls can be designed by proportioning the dimensions of the walls for a 9-inch flume.

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[1] Water Measurement Manual, Bureau of Reclamation, Second Edition, 1981.

- Parshall flumes should be installed with the throat centered about the horizontal centroid of the flow section. This improves the flow approach and measurement on unsymmetrical stream channels that concentrate flow to one side.

- Properly placing boulder clusters (fig. 1) at the midpoint of the maximum approach pool length can improve poor approach channel conditions and reduce the expected discharge error. The comparison of the best fit equations with the weir data (table 2) indicates that the boulder clusters reduce the mean percent deviation and standard deviation.

- For measurement sites with rough approach flow, flume head measurements should be made from a stilling well. In the laboratory tests, measuring head by visually reading the flume wall staff gauge resulted in head measurement errors of up to ±2.5 percent (table 4) as compared to using hook gauges and stilling wells. The associated discharge error is ±4 percent.

- The correlation coefficients in table 3 illustrate how the Parshall flumes can be calibrated for use in mountain streams. However, the equation coefficients and exponents are not the same as given by standard equations for tranquil flow.

- The standard deviations of the percent discharge (table 2) were equal to ±4.15 percent or less if they are specifically calibrated for the approach channel conditions. The maximum absolute deviation magnitude was about 10 percent for the mountain stream flow calibrations.

- The mean discharge error using the standard equation rather than the calibration for mountain use (table 3) was from about 1.7 to 6 percent. The standard deviation ranged from 3.5 to 5.86 percent and maximum percent absolute deviation from 8.7 to 22 percent.

LABORATORY TEST FACILITY

The Parshall flumes were installed in the end of a 16-foot-long by 8-foot-wide by 3-foot-deep fixed bed model (fig. 2). The horizontal crest of the flumes were placed 3 inches above the channel boundary. The lateral placement was determined by centering the flume about the centroid of the flow cross section at maximum flow. Channel roughness and slope were modeled from field site survey data and photographs. Material ranging from 3/8-inch gravel to 6-inch diameter cobbles were placed in the mortar bedding of the model (fig. 3). The model channel was placed on a constant slope of 0.1 ft/ft. Sandbags were used in the model to represent additional large boulders present at the field sites.

Partially contracted Kindsvater-type weirs were used in the model as the standard for discharge measurements. The equation coefficients for these weirs were determined from National Bureau of Standards criteria.[2] A Kindsvater-Shen V-notch weir (fig. 4) was used for measuring model flows below about 2 ft^3/s. To achieve an accuracy of ±1 percent at 1.0 ft^3/s required the associated head measurement on the weir to be accurate to within ±1 millimeter. Larger discharges were

[2] NBS Special Publication No. 421, A Guide to Methods and Standards for Measurement of Water Flow, G. Kulin and P. R. Compton, 1975.

measured using a Kindsvater-Carter rectangular weir. For the rectangular weir, head measurements within ±1.5 millimeters were needed to attain an accuracy of ±1 percent at 5 ft^3/s. To attain the potential Parshall flume accuracy of ±3 percent, the head measurements within the flume need to be measured within ±2 percent. Therefore, the study control heads were measured using hook gauges and stilling wells.

LABORATORY MEASUREMENTS

After assembling the Parshall flumes their dimensions were checked against standard dimensions for Parshall flumes. For both the 6- and 9-inch flumes, the convergence length was 1/8 inch too long and the throat widths were 1/8 inch too wide. These dimensions are critical if the standard calibration equations are to be applied.

During the laboratory tests, flume water depths were measured and compared using the following four methods:

1. Vernier hook gauge (0.001-ft divisions) in a 4-inch stilling well was read visually.

2. Staff gauges (0.01-ft divisions) were read visually.

3. Sight glass with a scale (1-mm divisions) was connected to the stilling well and read visually.

4. Float-tape system was placed in a 12-inch stilling well. The depth signal was connected to a digital output device.

INITIAL OBSERVATIONS

During initial test runs it was observed that approach channel flow was too fast and rough for making good staff gauge readings. Although, standard specifications do not require 45° wing walls for the 6-inch and smaller flumes, wing walls were added to the 6-inch to improve the approach conditions. The walls (fig. 5) were sized by proportion to those for the standard 9-inch flume. Observation of the 6-inch flume with and without the wing walls showed that they reduced the water surface fluctuations at the measuring station. Therefore, they were installed for all calibration test measurements. However, there were still strong flow contractions at the intersection of the 45° wings and vertical wall of the flume entrance which caused extensive water surface fluctuations in the flumes.

By experimenting it was found that approach flow conditions could be improved by partially blocking the approach channel with boulders at a distance one-half the maximum pool length upstream from the flume entrance (fig. 1).

In the model, sandbags were used to represent boulders (fig. 6). The bags were placed to a height of about three-fourths of the maximum pool depth at the sides leaving a low overflow section centered at the thalweg and at a level of about one-half the maximum pool depth. The length of the low overflow section was about one-third the total maximum flow pool width.

TEST RESULTS

The appendix lists the flume hook gauge stilling well head data and the associated weir discharge data for the complete study. These data were used as the standard for the statistical comparisons drawn in tables 1 through 4.

Table 1 lists the least squares fit coefficient, exponent and correlation coefficient for the equation form:

$$Q = \alpha H^{\beta}$$

Where: Q = discharge, ft^3/s
H = measuring head, ft
α,β = coefficient and exponent derived from least squares fit

The correlation coefficients indicate, even with the mountain stream approach conditions, Parshall flumes can be calibrated for heads measured in stilling wells. Therefore, the data support the use of Parshall flumes as accurate flow measurement structures for the mountain stream sites studied. This assumes the approach channels are cleared and boulders are placed as previously described to improve the stilling arrangement.

To evaluate the goodness of fit of each regression predictor equation, the deviations of discharge from regression were calculated for each data point. Weir discharges around the regression curves are shown on figures 7 to 10. The mean standard deviation from regression and the maximum absolute sample deviation are listed in table 2. The deviation of the data about the regression lines were compared to evaluate the performance of the boulder cluster technique implemented in the calibration tests. Use of the boulder cluster reduced the mean percent error and the standard deviation of the percent error for the discharge readings. It is expected that for normally distributed data, 99.7 percent of data are within ±3 standard deviations. Therefore, any data outside of this range were not used in the fits and considered as misread. For the 9-inch flume the boulder cluster reduced the standard deviation a percentage point and the maximum deviation was increased by 2 percentage points. However, the maximum absolute deviation magnitudes were about the same with the boulder cluster and without. The 6-inch flume did not have as much improvement. Although the maximum absolute deviation was reduced by 2 percentage points, here again the magnitudes were about the same.

Table 3 lists the mean, standard deviation and the maximum discharge sample deviation from the standard Parshall flume equations using the measured heads. A comparison of the deviations between tables 2 and 3 show an overall reduction in the percent discharge error using the laboratory calibration equations in table 1. These comparisons clearly show the need to provide special calibrations for mountain stream use.

The data in table 4 compare the different methods used to measure heads relative to the hook gauge and well measurements. The hook gauge can discriminate the water surface to within ±0.002 ft. The data show that using a staff gauge instead of a hook gauge and a well in a cleared mountain stream channel increases head errors 3 to 5 percent. Adding the boulder stilling cluster in the cleared channel decreased the error range 1.75 to 2.5 percent. The same error ranges in terms of discharge are 4.5 to 7 percent and 3 to 4 percent, respectively.

Table 1. - Calibration curves developed from laboratory tests ($Q = \alpha H^{\beta}$)

Flume size/boulders clustered in channel	Coefficient α	Exponent β	Correlation coefficient
9-inch/yes	3.0410	1.5610	0.99924
9-inch/no	3.0491	1.5798	0.99938
6-inch/yes	2.1170	1.6032	0.99762
6-inch/no	2.1893	1.6804	0.99892
9-inch/no	3.07	1.53	(standard Parshall flume equation)
6-inch/no	2.06	1.58	(standard Parshall flume equation)

Table 2. - Comparison of percent error between equation fit discharge and weir discharge, 100 (eq. Q - weir Q)/weir Q

Flume size/boulders clustered in channel	Mean % deviation	Standard deviation of % deviations	Maximum % deviation
9-inch/yes	0.078	3.01	-10.6
9-inch/no	0.104	4.15	8.53
6-inch/yes	0.072	3.51	-6.54
6-inch/no	0.095	3.65	-8.54

Table 3. - Comparison of percent deviation between standard Parshall flume equation discharge (stan. Q) and weir discharge, 100 (stan. Q - weir Q)/Weir Q.

Flume size/boulders clustered in channel	Mean % deviation	Standard deviation of % deviations	Maximum % deviation
9-inch/yes	3.49	4.33	15.3
9-inch/no	6.09	6.09	22.0
6-inch/yes	-1.79	3.46	-8.7
6-inch/no	1.67	5.79	22.2

Table 4. - Comparison of different head measuring methods

Flume size/ boulders clustered in channel	Method	Mean percent head error	Standard deviation	Maximum absolute head error
9-inch/yes	Staff	1.78	2.26	6.86
	Sight glass scale	-0.06	1.01	2.28
	Digital recorder	1.02	1.14	4.21
9-inch/no	Staff	4.71	1.24	6.72
	Sight glass scale	-0.34	3.03	7.34
6-inch/yes	Staff	2.43	1.92	5.61
	Sight glass scale	0.53	0.63	1.87
6-inch/no	Staff	2.86	5.72	13.3
	Sight glass scale	-0.01	0.50	0.88

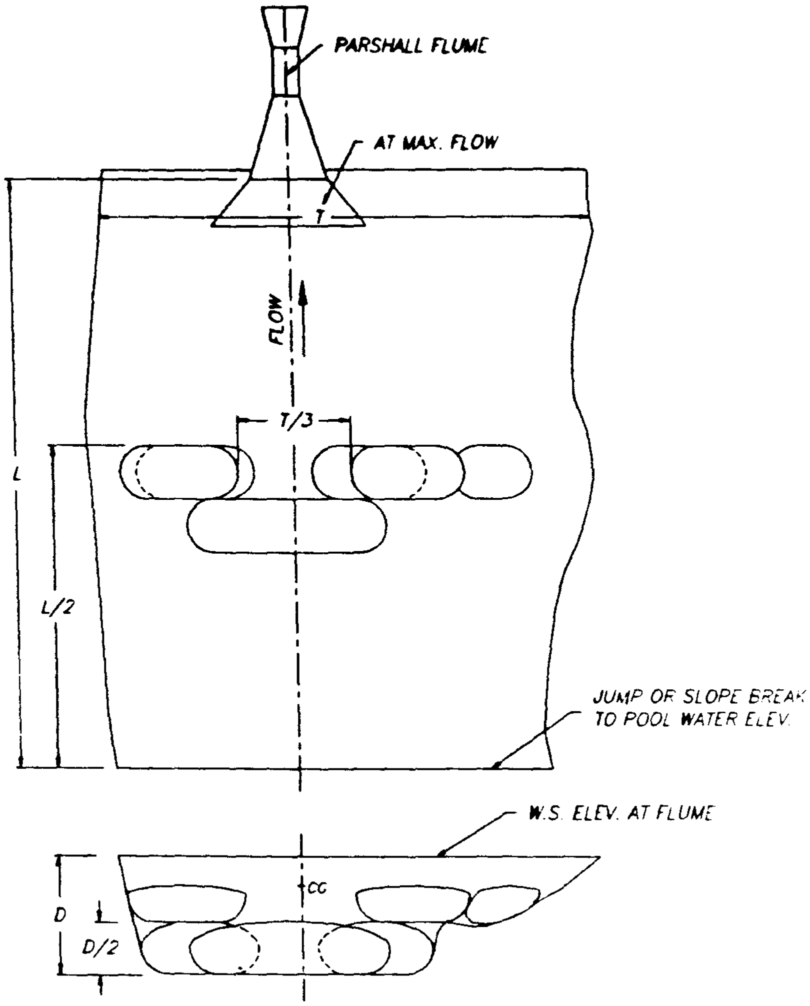

Figure 1. - Placement of boulders in stream channel.

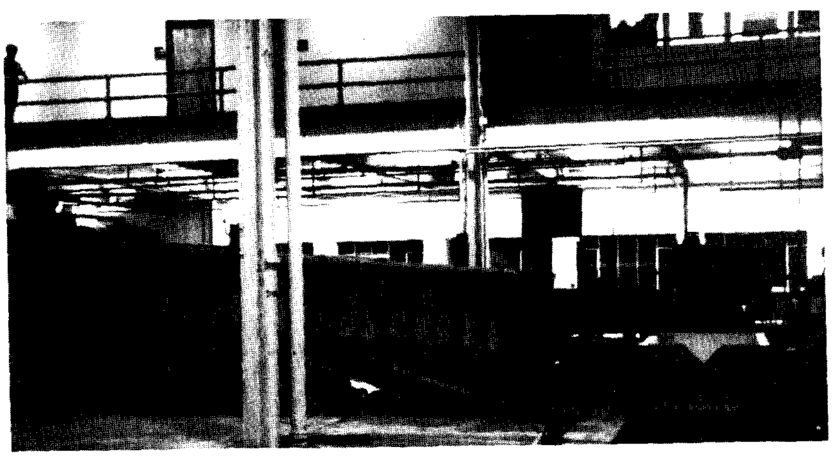

Figure 2. - The 16-foot-long test facility with Parshall flume and V-notch weir.

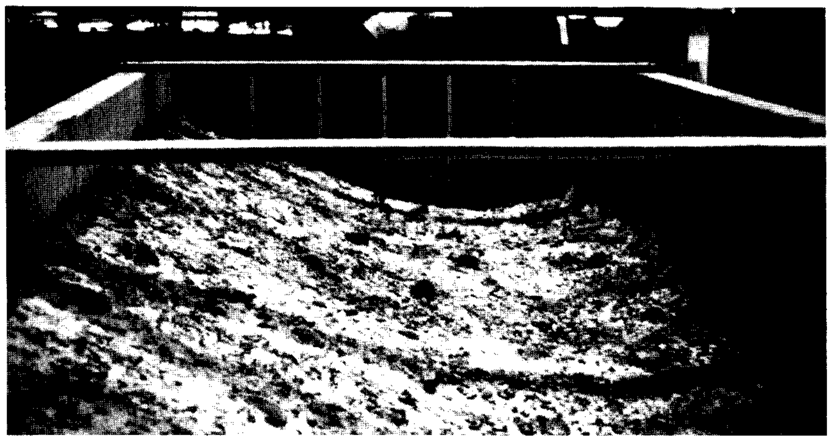

Figure 3. - Looking upstream at cobble roughness embedded in mortar.

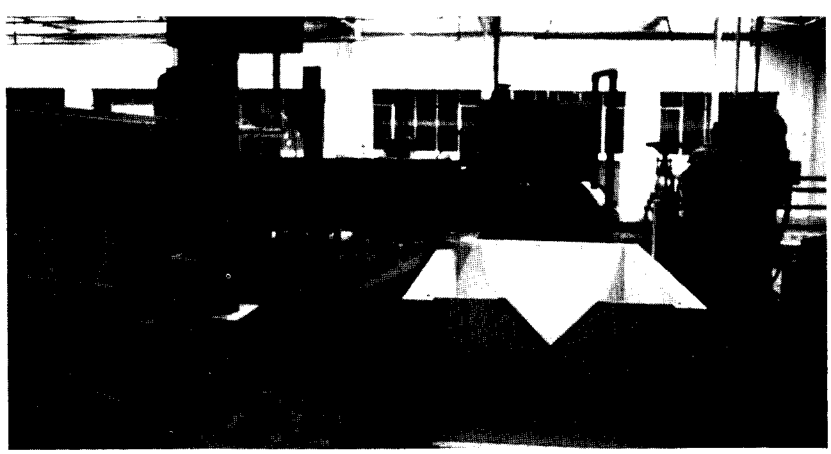

Figure 4. - Closeup view of V-notch weir.

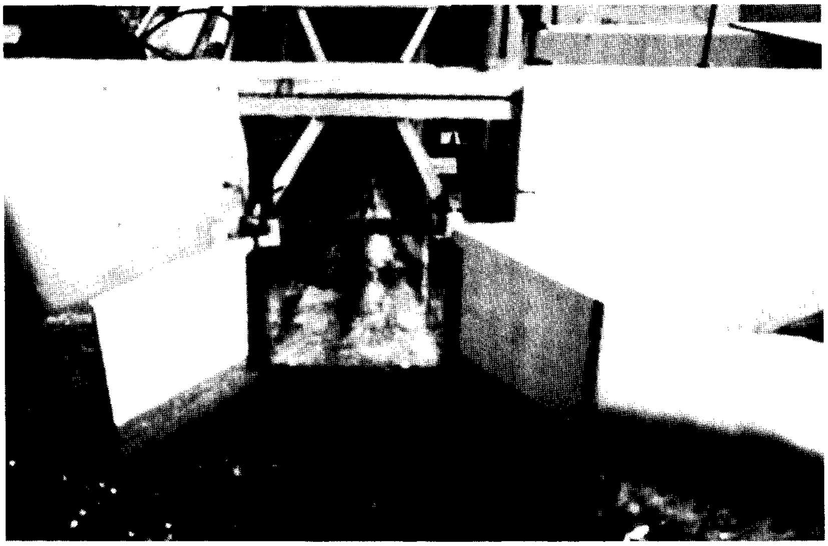

Figure 5. - Downstream view of wing walls at entrance to 6-inch flume.

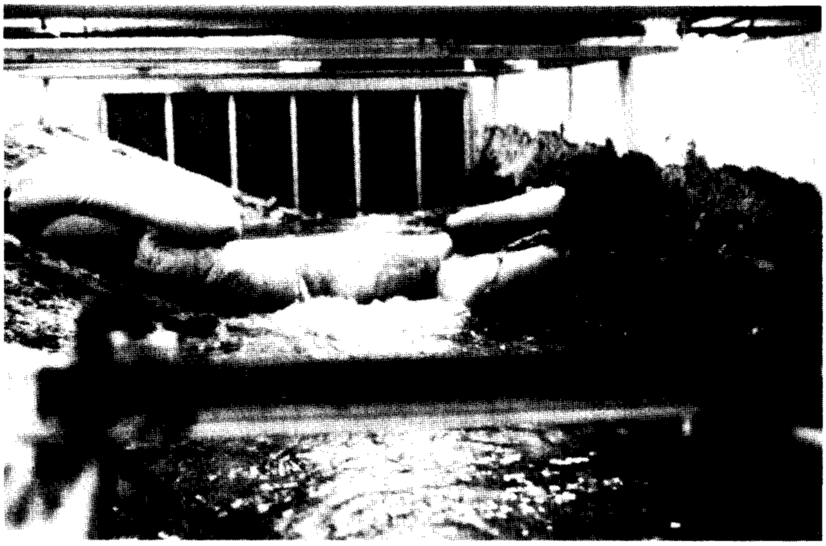

Figure 6. - Looking upstream at sandbags representing boulders.

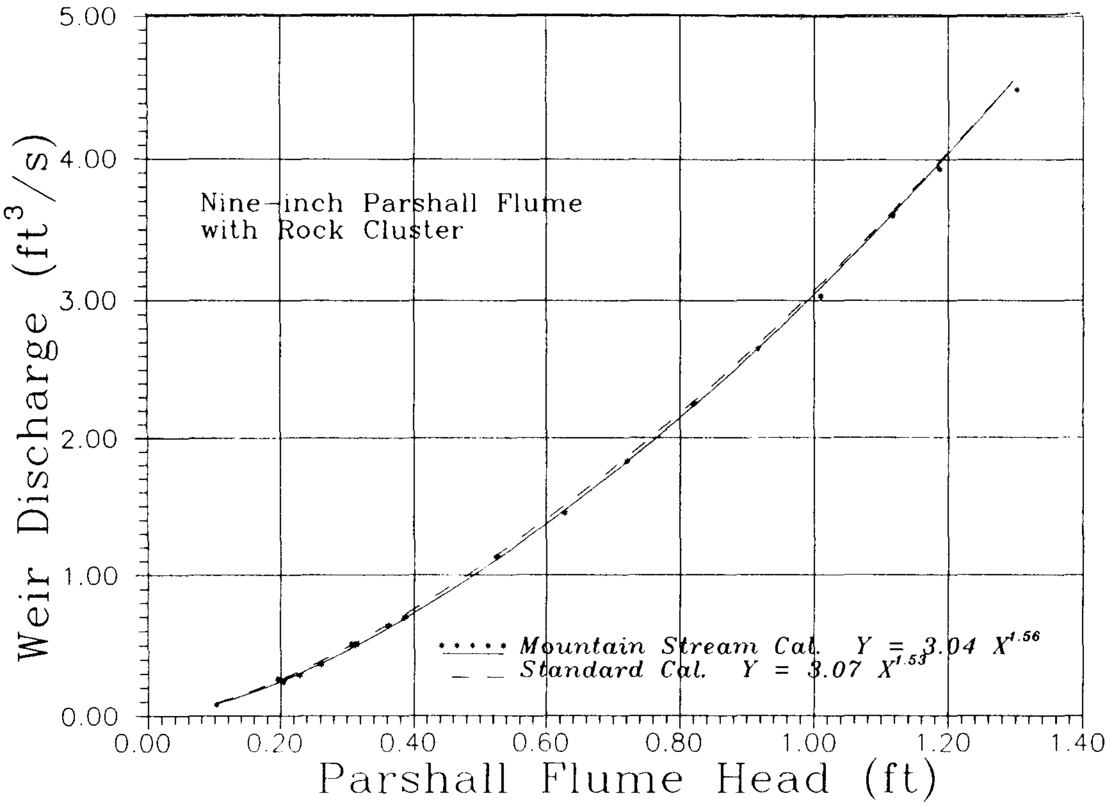

Figure 7. - Calibration for 9-inch Parshall flume with rock cluster.

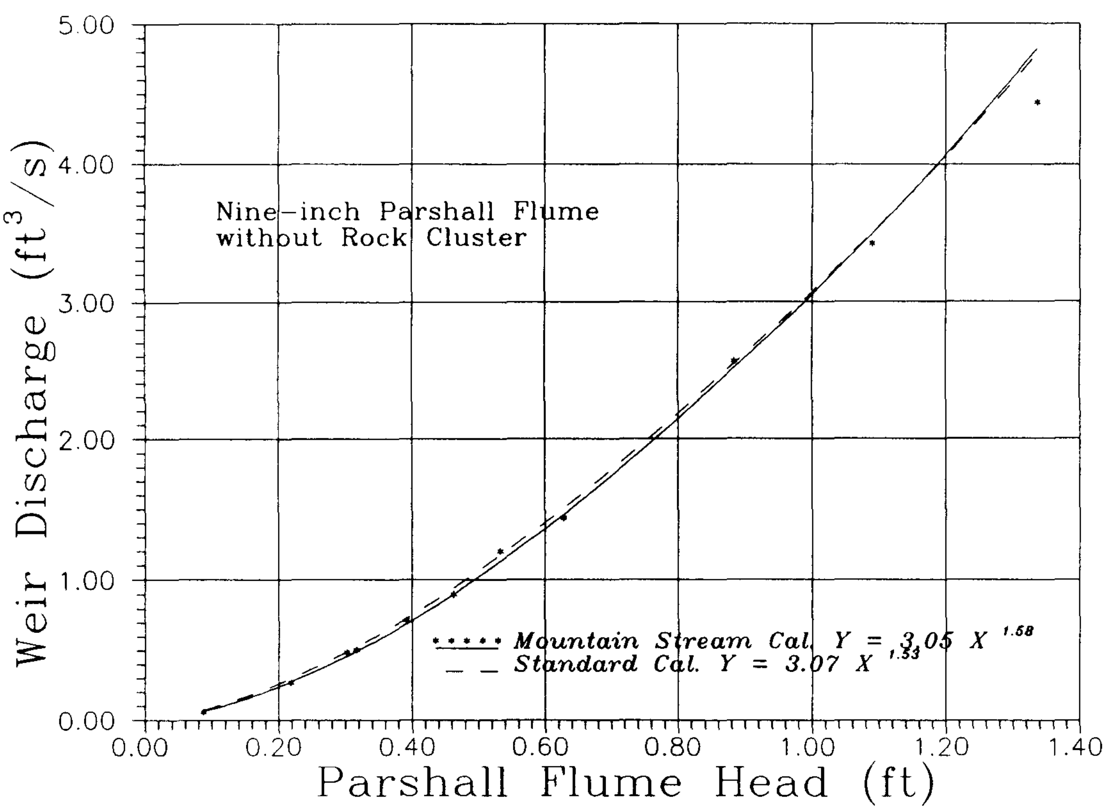

Figure 8. - Calibration for 9-inch Parshall flume without rock cluster.

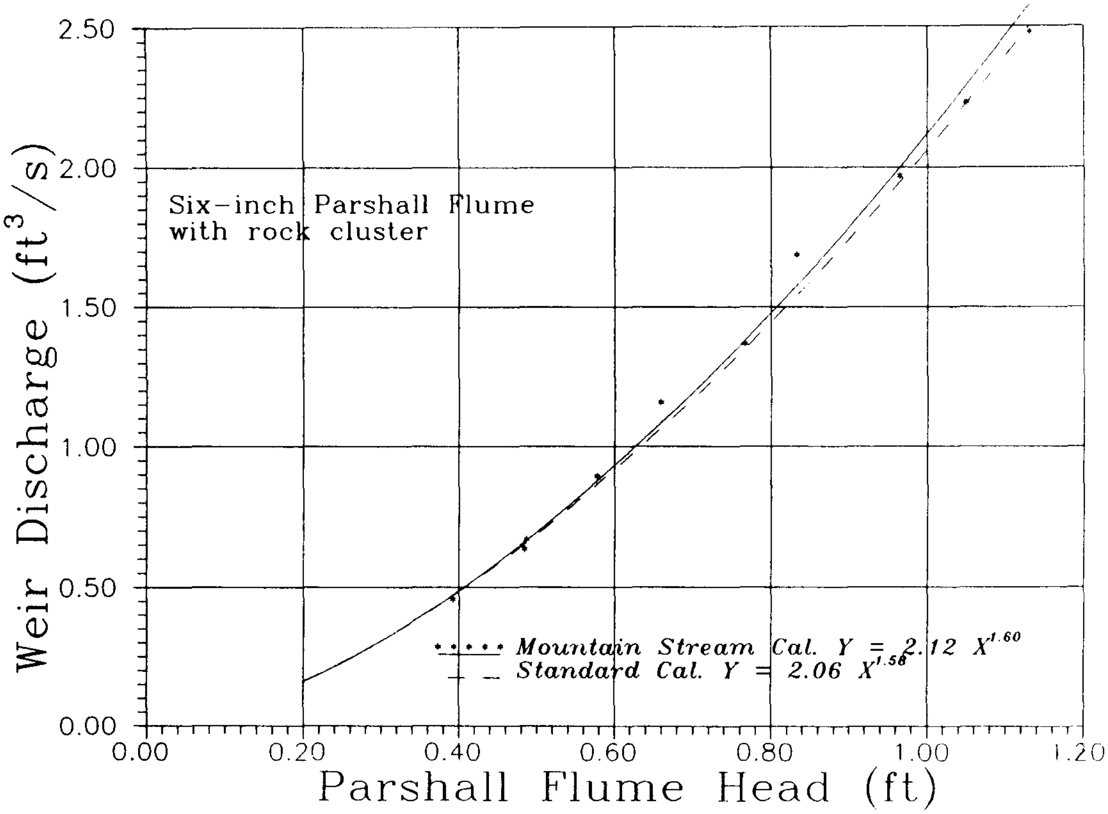

Figure 9. - Calibration for 6-inch Parshall flume with rock cluster.

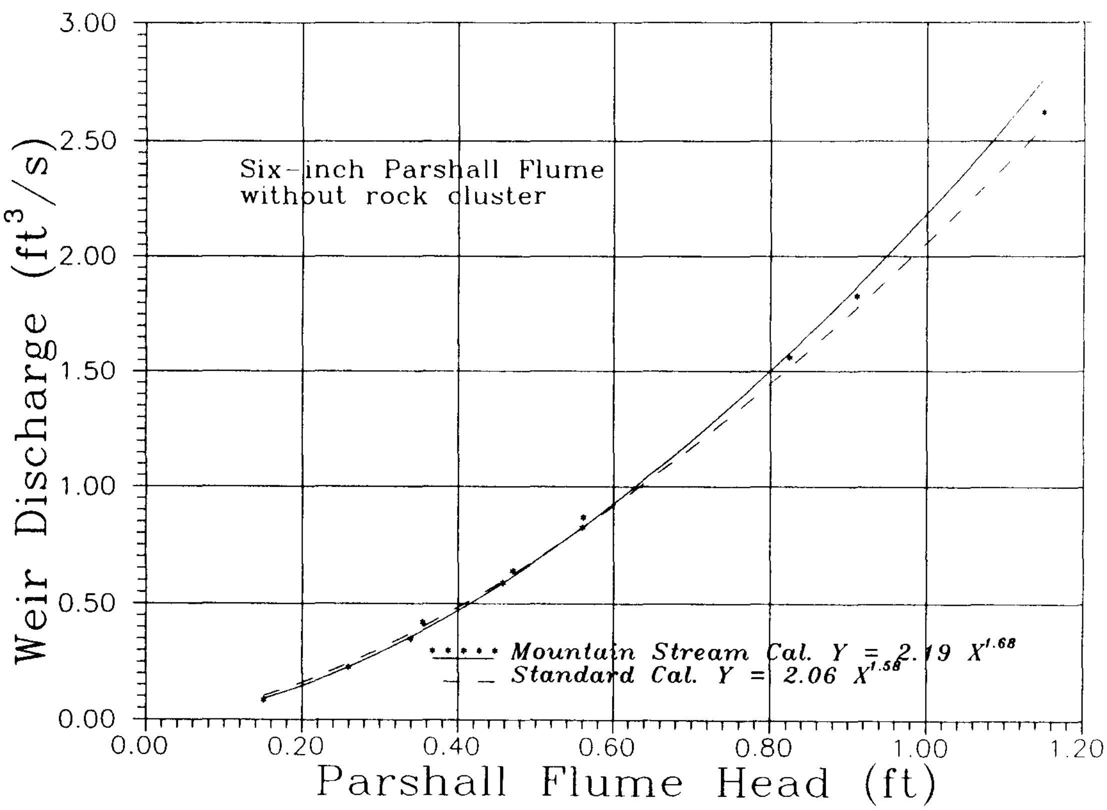

Figure 10. - Calibration for 6-inch Parshall flume without rock cluster.

APPENDIX

Parshall flume head-discharge data

Nine-inch flume

Boulders		No Boulders	
Head (ft)	Discharge (ft^3/s)	Head (ft)	Discharge (ft^3/s)
0.307	0.510	0.087	0.060
1.302	4.500	0.219	0.272
1.187	3.920	0.316	0.507
1.116	3.600	0.463	0.903
0.916	2.650	1.336	4.440
0.721	1.830	0.884	2.560
0.628	1.450	0.628	1.440
0.525	1.130	0.533	1.200
0.362	0.640	0.392	0.720
0.386	0.700	0.302	0.490
0.195	0.265	1.090	3.420
0.313	0.505		
0.229	0.290		
0.102	0.081		
0.261	0.367		
0.204	3.030		
1.010	2.250		

Six-inch flume

Boulders		No Boulders	
Head (ft)	Discharge (ft^3/s)	Head (ft)	Discharge (ft^3/s)
0.392	0.457	1.149	2.620
0.484	0.636	0.911	1.830
0.486	0.670	0.824	1.560
0.659	1.160	0.561	0.870
0.766	1.370	0.470	0.640
0.833	1.690	0.355	0.420
0.965	1.970	0.560	0.826
1.050	2.230	0.457	0.590
1.131	2.480	0.340	0.350
0.578	0.895	0.260	0.228
		0.151	0.085

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